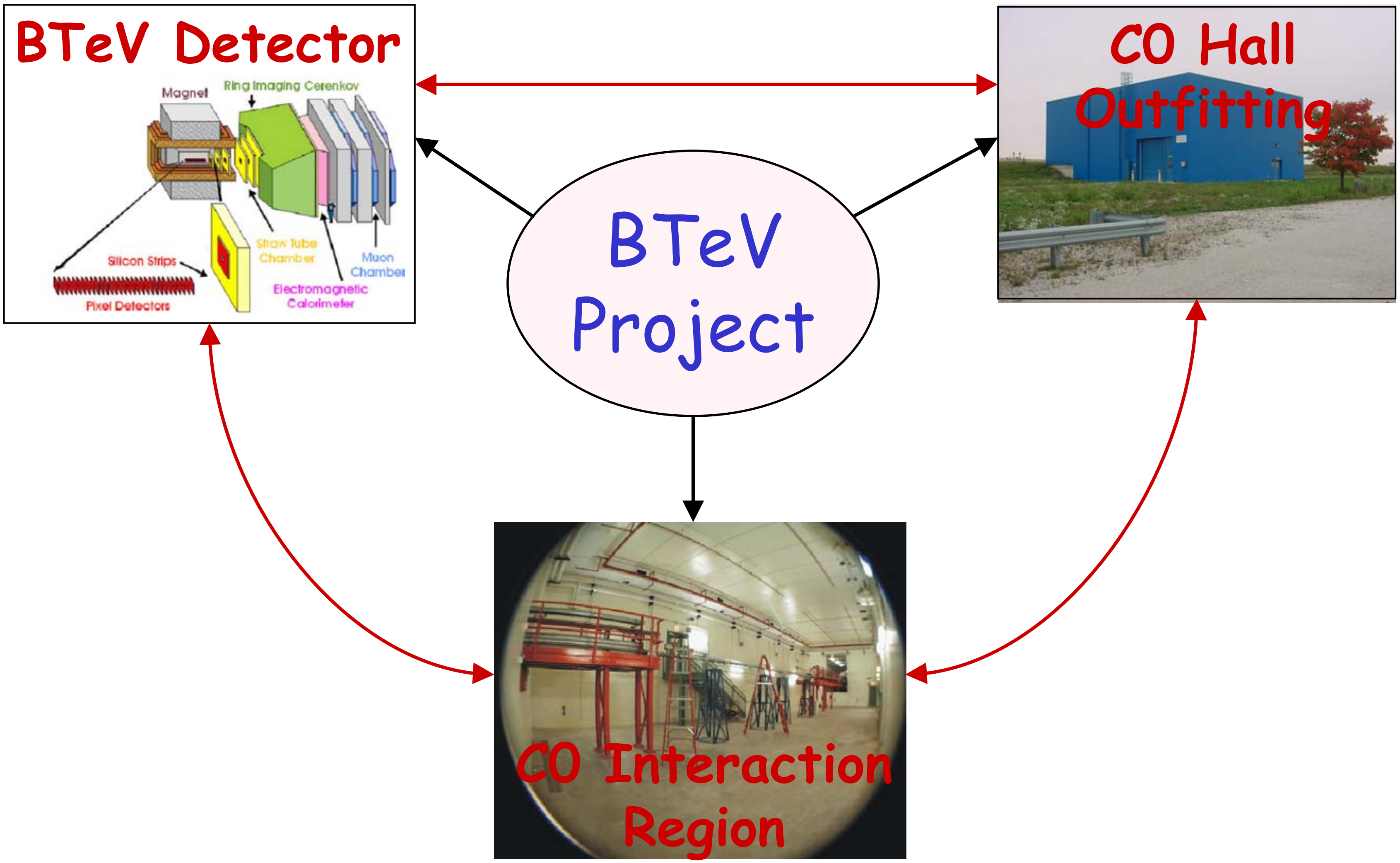
General Overview of the BTeV Project and its Requirements

Project Components



Requirements on C0 IR

- Peak Luminosity ~2×10^{32} cm^{-2} s^{-1}
- Interoperability: Must allow for operation at C0 or at B0 & D0 simultaneously
- Non-interference with BTeV detector – last quadrupole closest to collision point is 5 m further away than in CDF or D0
- Schedule: Must be ready by shutdown in middle of 2009

BTeV Collaboration

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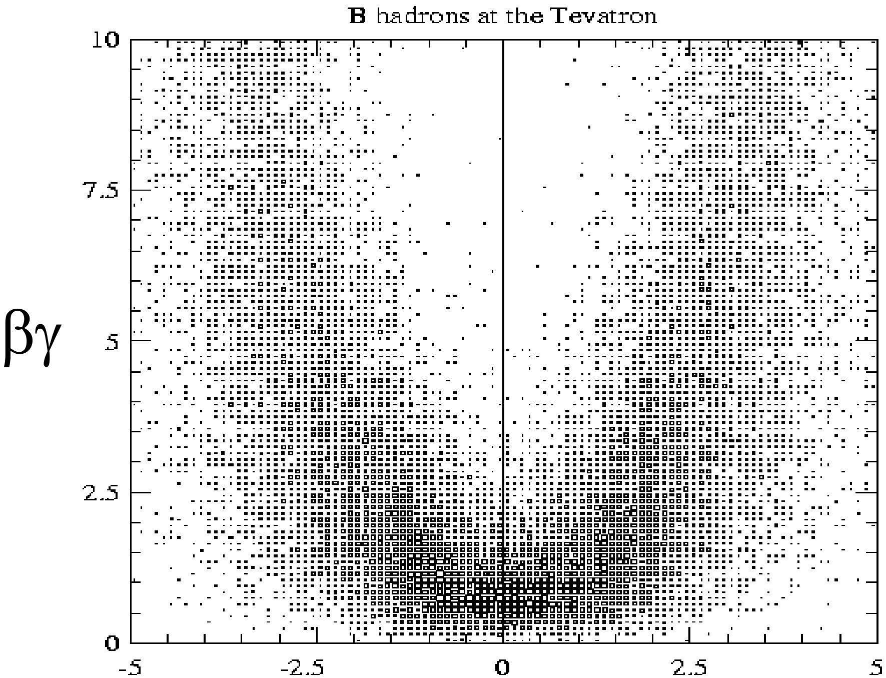
Characteristics of hadronic b production

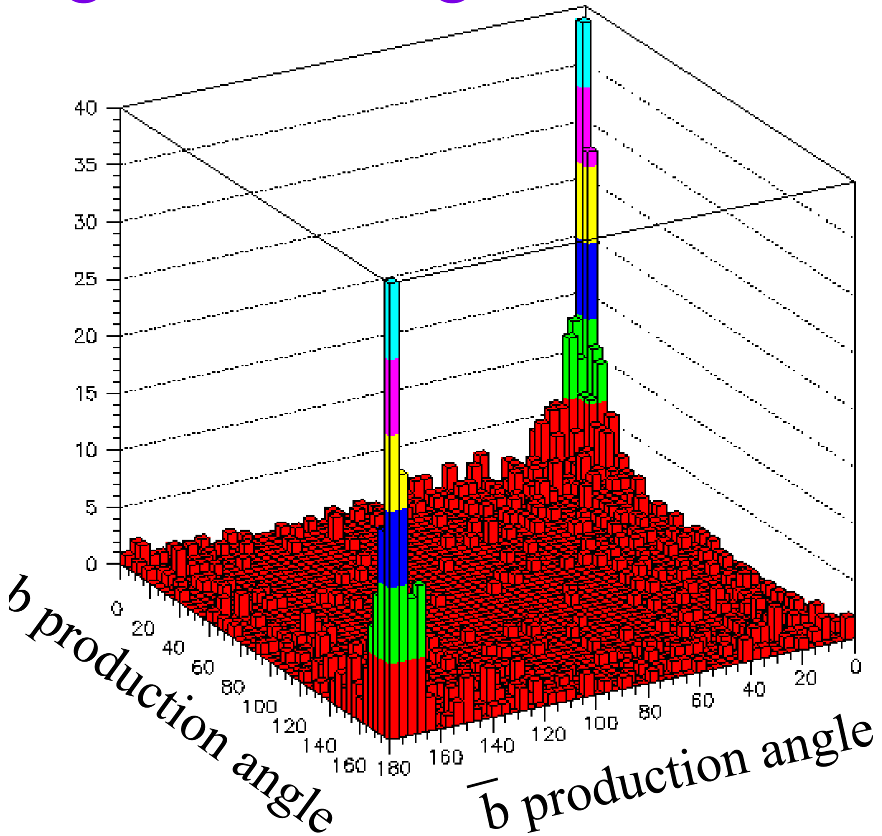
$$p\bar{p} \rightarrow b\bar{b} + X$$

The higher momentum b's are at larger η's



$$\eta = -\ln(\tan\frac{\theta}{2})$$

b production peaks at large angles with large $\bar{b}b$ correlation



Requirements: General

- Intimately tied to Physics Goals
- In general, within the acceptance of the spectrometer (10 – 300 mr with respect to beam) we need to:
  - Detect charged tracks & measure their 3-momenta
  - Measure the point of origin of the charged tracks (vertices)
  - Detect neutrals & measure their 3-momenta
  - Reveal the identity of charged tracks (e, μ, π, K, p)
  - Trigger & acquire the data (DAQ)
- Need to do as well as possible – we want individual subsystem to even exceed their performance specs, within the budget constraints

Basics Reasons for the Requirements

- B's (& D's) are long lived, ~1.5 ps, so if they are moving with reasonable velocity they go ~3 mm before they decay. This allows us to Trigger on the the presence of a B decay (*detached vertex*).
- B's are produced in pairs $p\bar{p} \rightarrow b\bar{b}+X$, and for many crucial measurements we must detect one b fully and some parts of the other: "flavor tagging"
- Physics states of great interest now are varied and contain both charged and neutrals, B_d & B_s

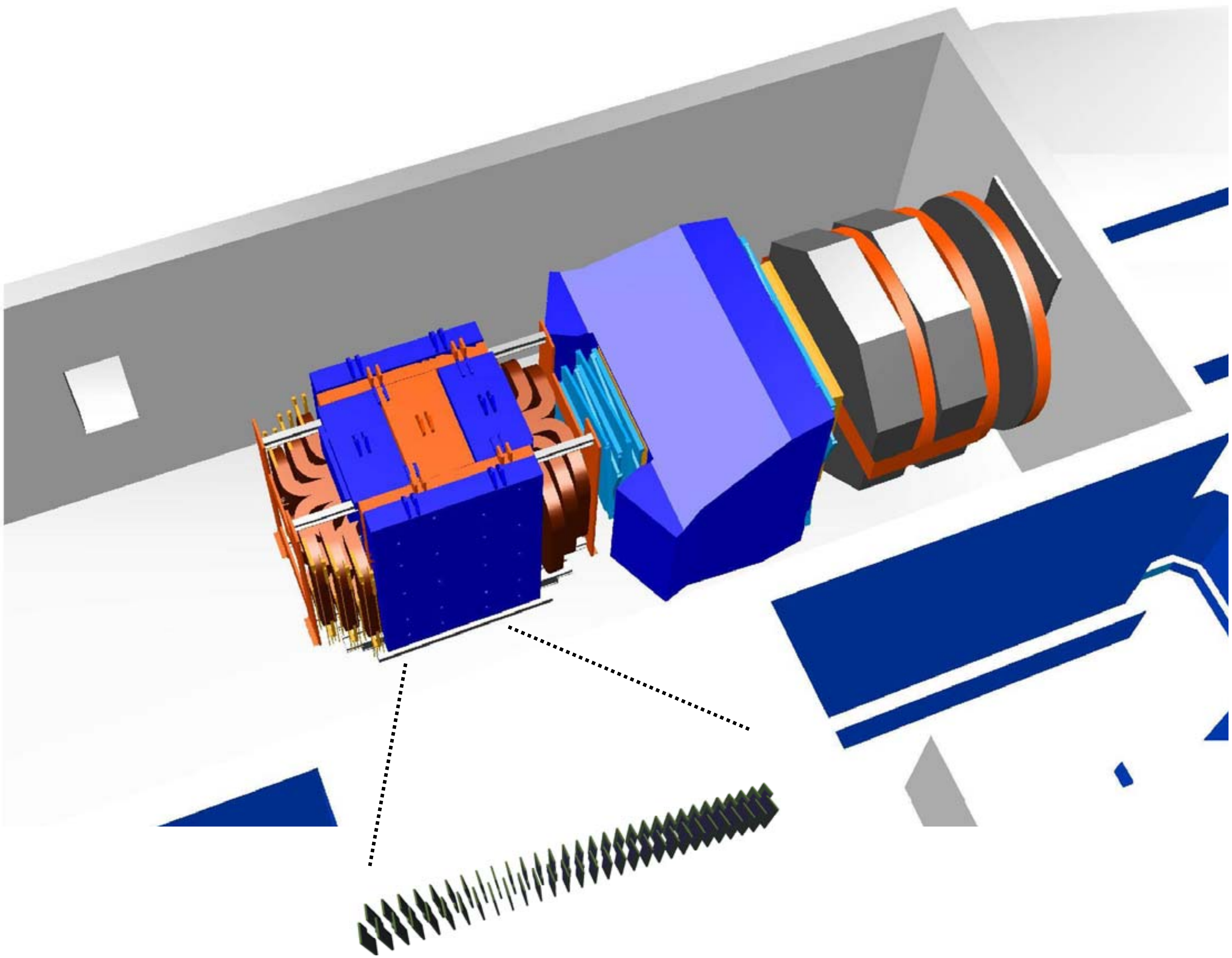
Summary of required measurements for CKM tests

Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\sin(2\alpha)$	$B^o \to \pi^+\pi^-$ & $B_s \to K^+K^-$	✓	✓		✓
$\cos(2\alpha)$	$B^o \to \rho\pi \to \pi^+\pi^-\pi^o$	✓	✓	✓	
$\mathrm{sign}(\sin(2\alpha))$	$B^o \to \rho\pi$ & $B^o \to \pi^+\pi^-$	✓	✓	✓	
$\sin(\gamma)$	$B_s \to D_s K^-$	✓	✓		✓
$\sin(\gamma)$	$B^o \to D^o K^-$	✓	✓		
$\sin(\gamma)$	$B \to K \pi$	✓	✓	✓	
$\sin(2\chi)$	$B_s \to J/\psi\eta'$, $J/\psi\eta$		✓	✓	✓
$\sin(2\beta)$	$B^o \to J/\psi K_s$				
$\cos(2\beta)$	$B^o \to J/\psi K^*$ & $B_s \to J/\psi\phi$		✓		
x_s	$B_s \to D_s\pi^-$	✓	✓		✓
$\Delta\Gamma$ for B_s	$B_s \to J/\psi\eta'$, K^+K^-, $D_s\pi^-$	✓	✓	✓	✓

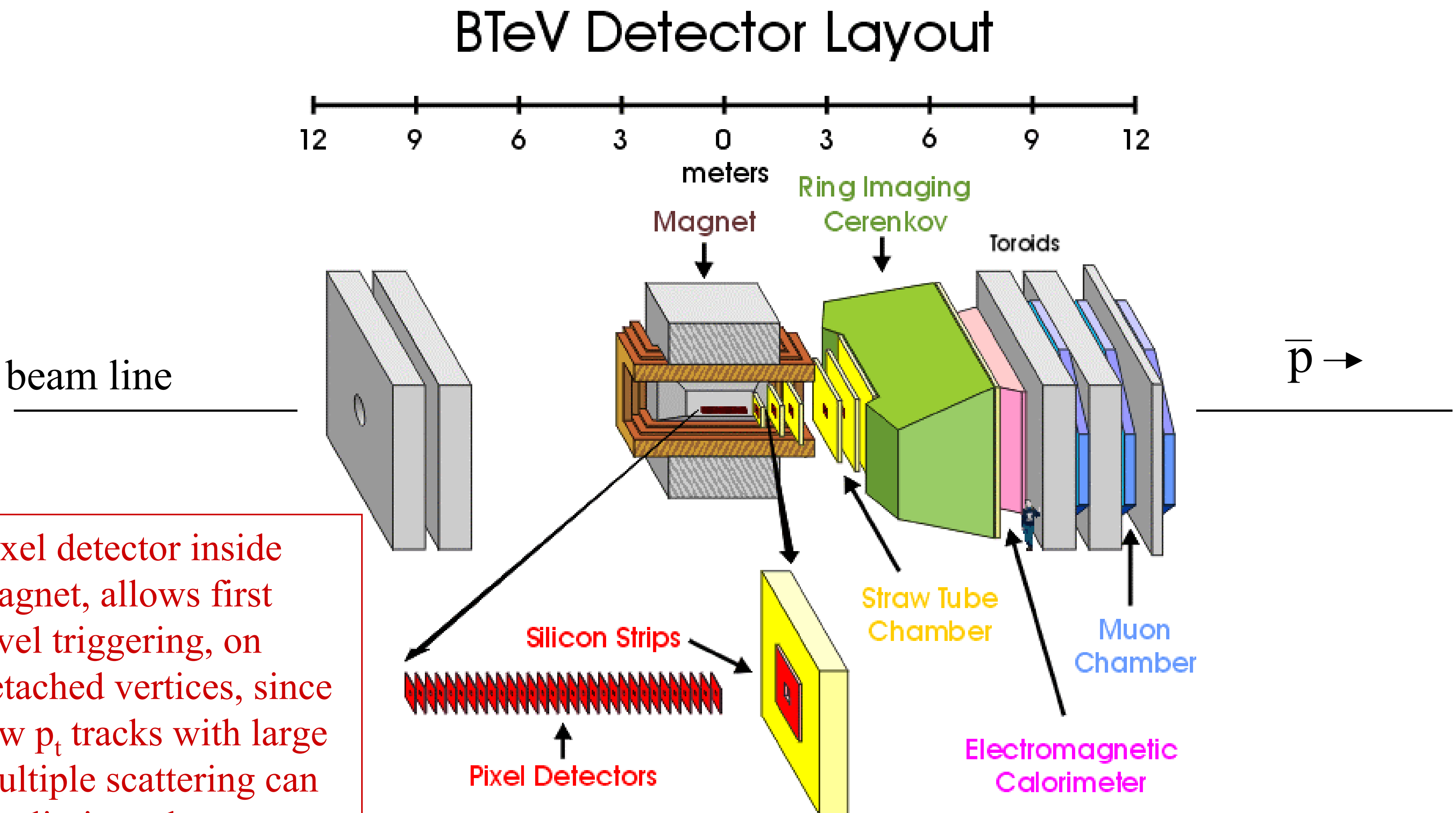
More Basic Reasons

- Many modes contain γ, π^o & η, so need excellent electromagnetic calorimetery
- B_s oscillations are fast, so need excellent time resolution ~<50 fs, compared to ~1500 fs lifetime. Also very useful to reduce backgrounds in reconstructed states
- Physics Backgrounds from $\pi \Leftrightarrow K$ can be lethal
  - $B_s \rightarrow D_s\ \pi^-$ is 15X $B_s \rightarrow D_s\ K^-$
  - $B^o \rightarrow K^* \pi \rightarrow K^{\mp} \pi^{\pm} \pi^o$ is 2X $B^o \rightarrow \rho\pi \rightarrow \pi^+ \pi^- \pi^o$
  - So excellent charged hadron identification is a must

The BTeV detector in the C0 collision hall



The BTeV Detector



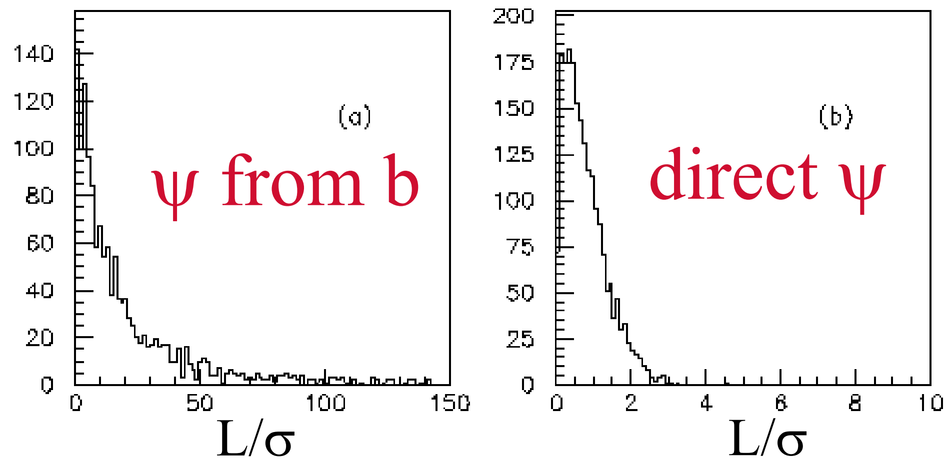
Pixel detector inside magnet, allows first level triggering, on detached vertices, since low p_t tracks with large multiple scattering can be eliminated

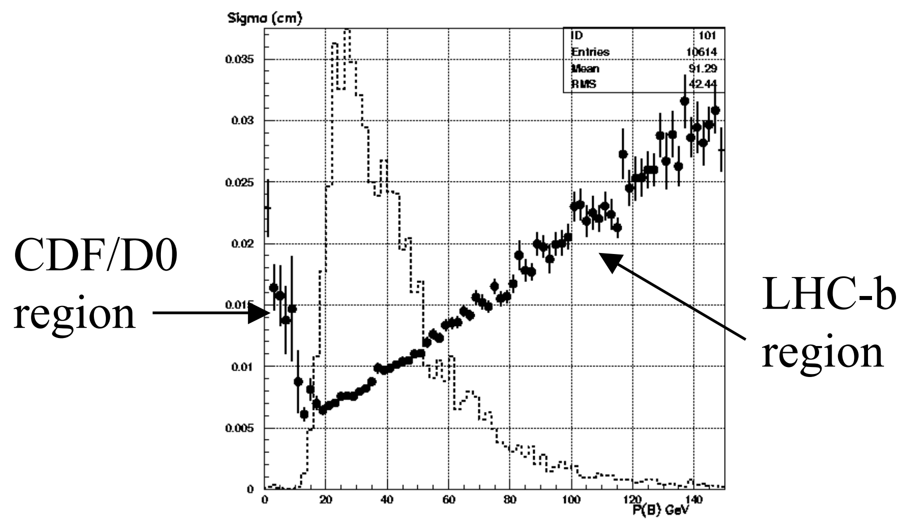
Fundamentals: Decay Time Resolution

- Excellent decay time resolution
  - ➢ Reduces background
  - ➢ Allows detached vertex trigger
- The average decay distance and the uncertainty in the average decay distance are functions of B momentum:

$\langle L \rangle = \gamma\beta c\tau_B$

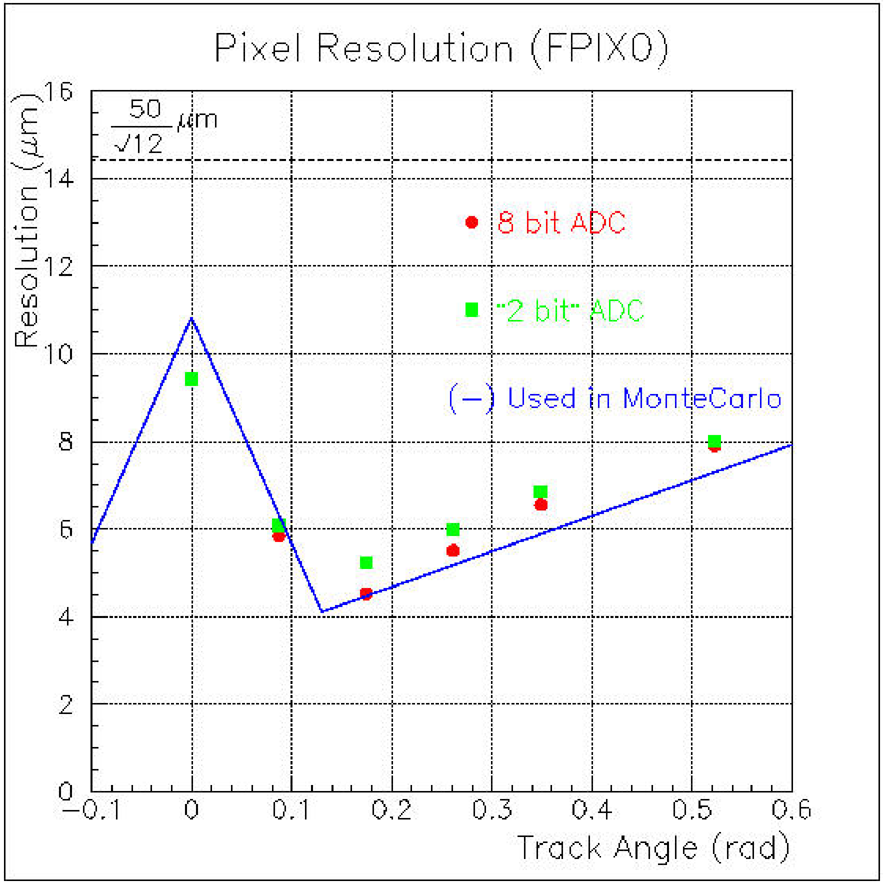
$= 480\ \mu m \times p_B/m_B$





Pixels

- Pixel – working systems studied in beams, including "almost" final electronics
- Full mechanical design done and being tested
- Pixels are inside of beam pipe in machine vaccum – OK with accelerator provided the outgassing rate is below specified limits (review document linked to Review web page)

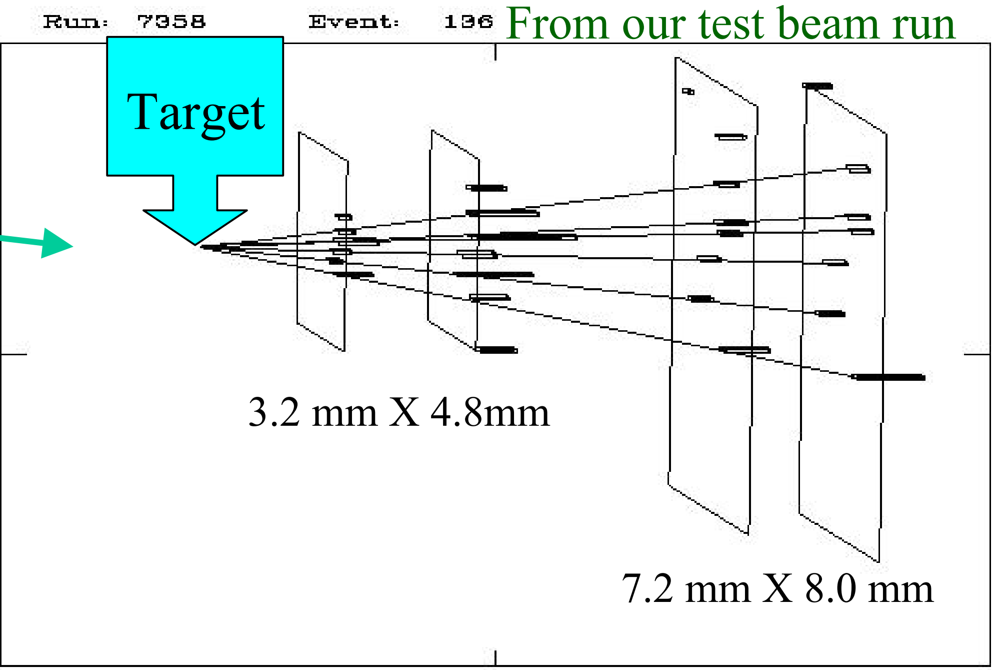


Physics Simulations Tools

- Full GEANT has multiple scattering, bremsstrahlung, pair conversions, hadronic interactions and decays in flight; smears hits and refits the tracks using "Kalman Filter." No pattern recognition (except for trigger). However, we do not expect large pattern recognition problems

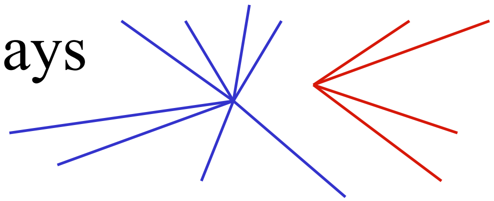
- **This track density is 10x higher than what is expected in BTeV!**

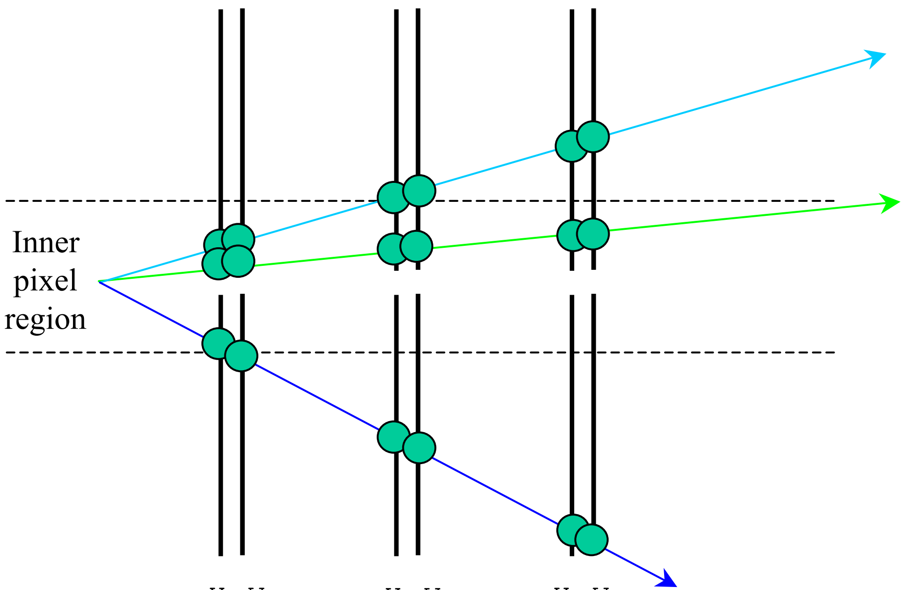
◆Detailed studies of efficiency and rejection for up to an average of six interactions/crossing



Pixel Trigger Overview

◆ Idea: find primary vertices & detached tracks from b or c decays





- Pixel hits from 3 stations are sent to an FPGA tracker that matches "interior" and "exterior track hits
- Interior and exterior triplets are sent to a farm of DSPs to complete the pattern recognition:
  - interior/exterior triplet matcher
  - fake-track removal

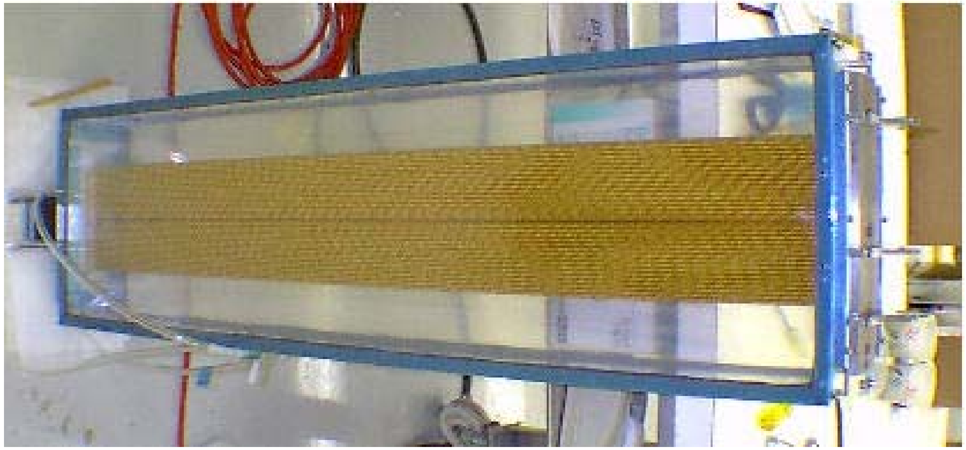
Trigger Performance

- For a requirement of at least 2 tracks detached by more than 4σ, we trigger on only 1% of the beam crossings and achieve the following efficiencies for these states at Level I:

State	efficiency(%)	state	efficiency(%)
$B \rightarrow \pi^+\pi^-$	55	$B^o \rightarrow K^+\pi^-$	54
$B_s \rightarrow D_s K$	70	$B^o \rightarrow J/\psi\ K_s$	50
$B^- \rightarrow D^o K^-$	60	$B_s \rightarrow J/\psi K^*$	69
$B^- \rightarrow K_s \pi^-$	40	$B^o \rightarrow K^*\gamma$	40

Tracking

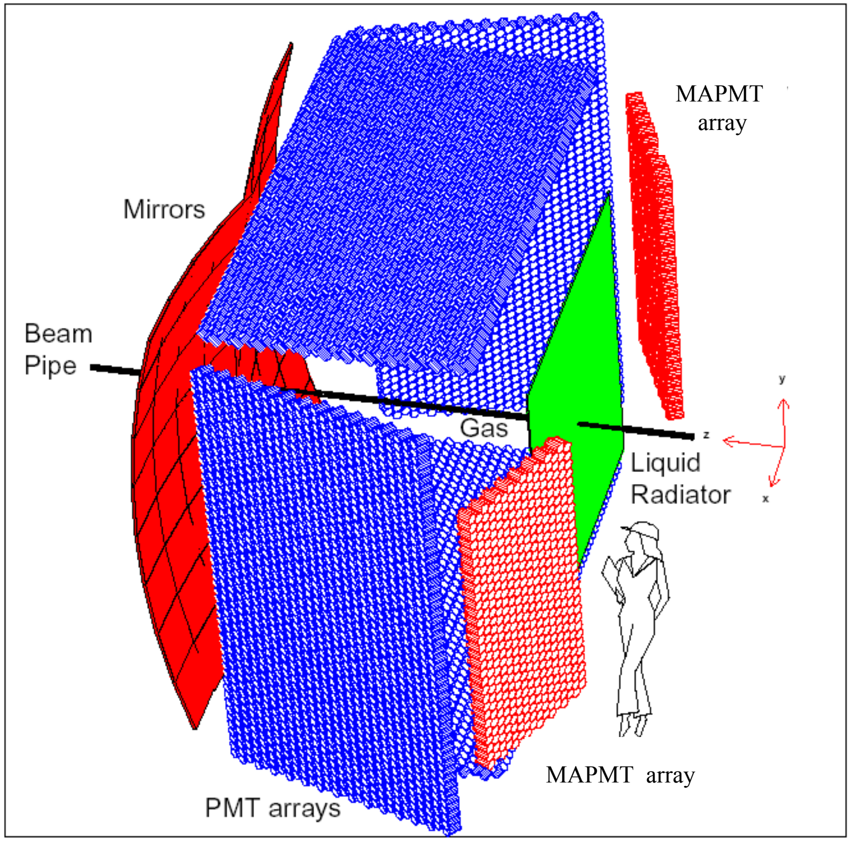
- Straws – protoype awaiting tests, uses Atlas design as basis



- Silicon Strips: simple single sided design, mechanics done.

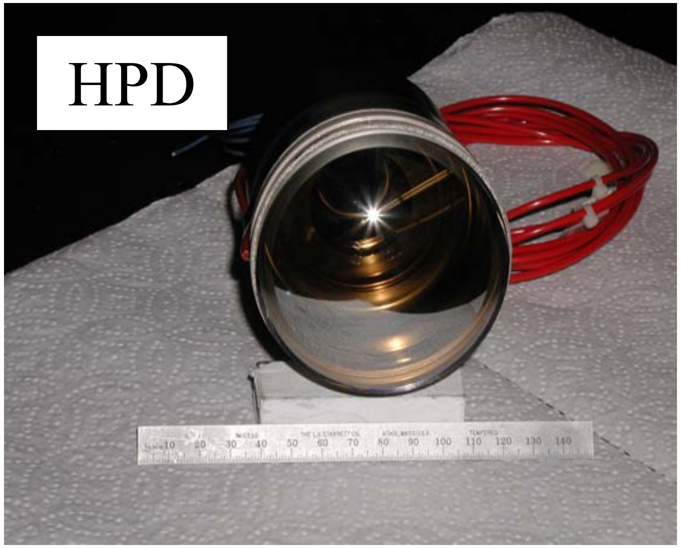
RICH: Two Systems

- Gas + Mirror + MAPMT to identify b decay products
- Liquid + PMT's to help with flavor tagging of b's (p/K separation for p < 9 GeV/c)
- Excellent particle id. distinguishes BTeV from "Central pp Detectors"



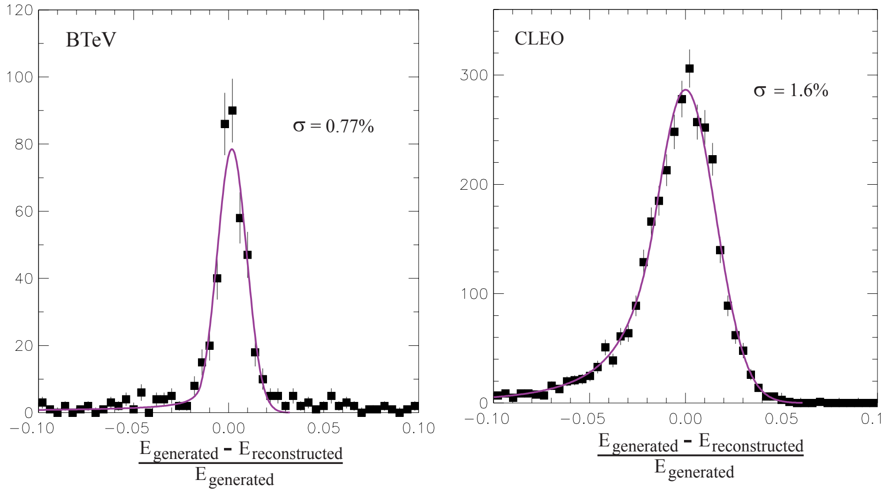
MAPMT vs. HPD

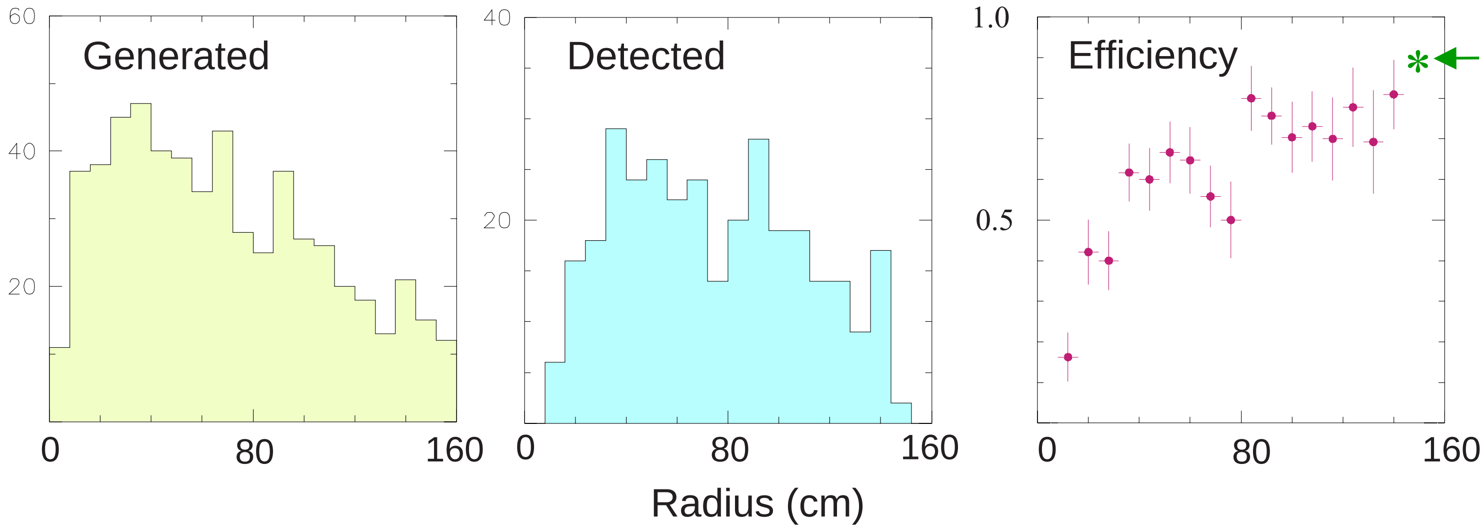
- A good situation: two viable technologies:
  - ➢ Hamamatusu has now produced an MultiAnodePMT with small borders
  - ➢ We have developed with DEP a 163 channel HPD & electronics that yields ~identical performance
- Currently
  - ➢ MAPMT's significantly cheaper due to currency exchange changes
  - ➢ MAPMT's easier to operate
- Baseline is now MAPMT's, but choice can be changed at time of construction if costs change



EM calorimetry using $PbWO_4$ Crystals

- GEANT simulation of $B^o \to K^* \gamma$, for BTeV & CLEO
- Isolation & shower shape cuts on both





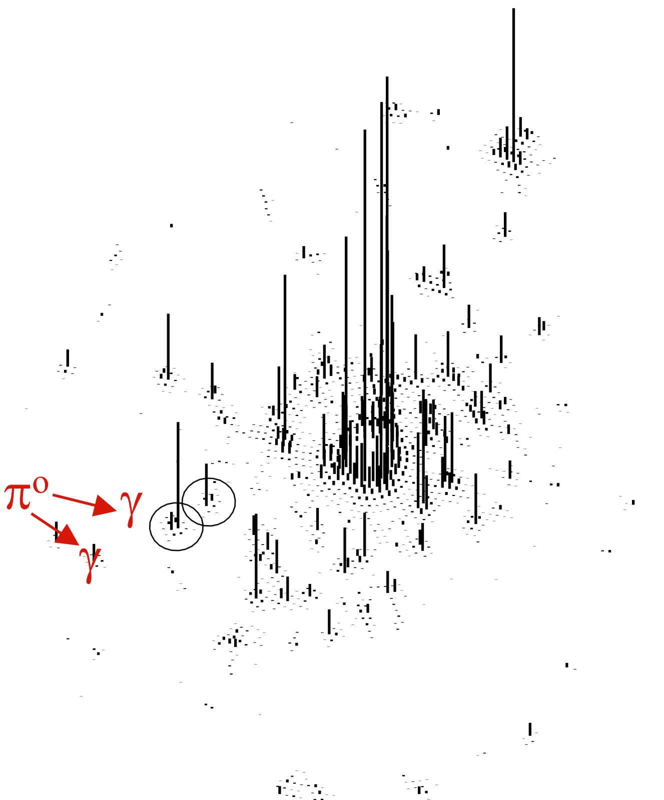
CLEO barrel ε=89%

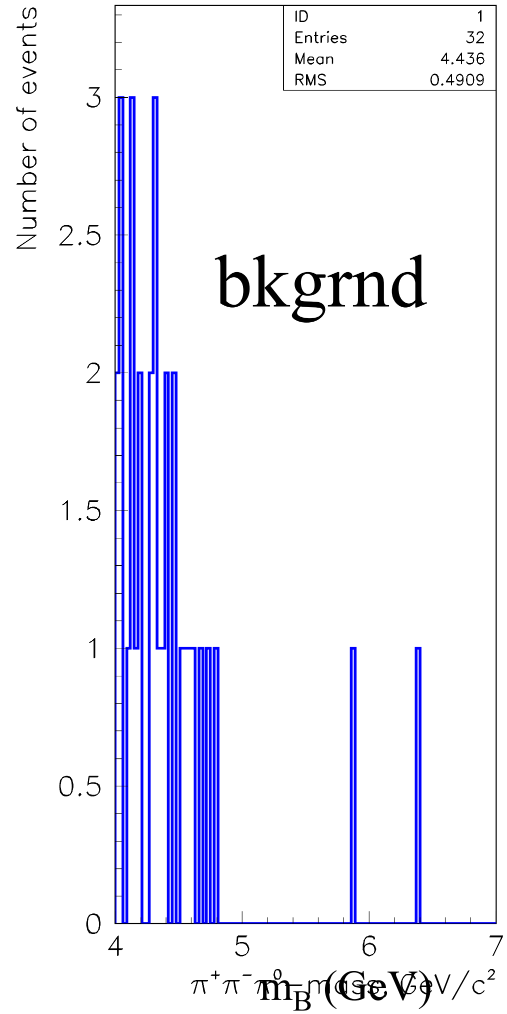
$B^o \to \rho\pi$

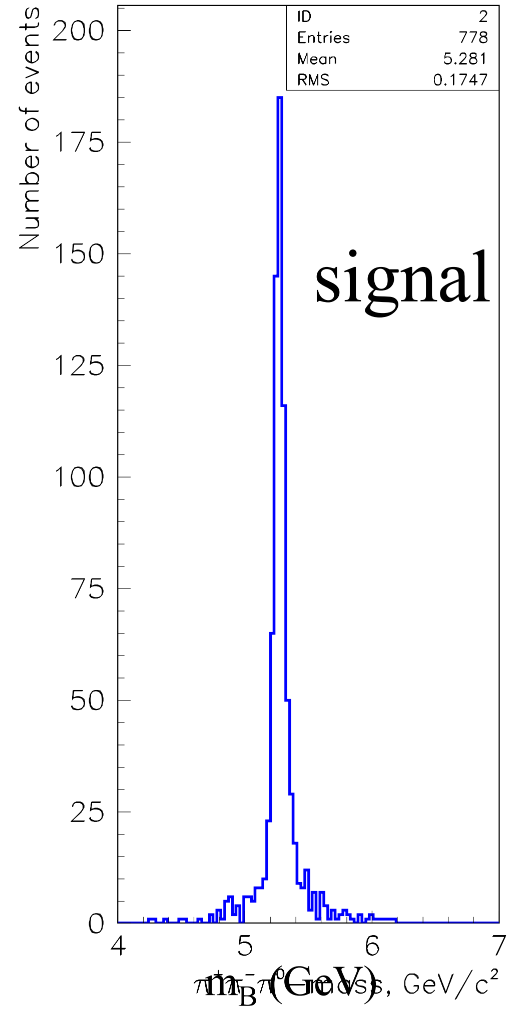
Based 9.9×10^6 bkgrnd events

$B^o \to \rho^+\pi^-$ S/B = 4.1

$B^o \to \rho^o\pi^o$ S/B = 0.3







Muon System

- Used to check detached vertex trigger by having an independent di-muon trigger
- Also used for μ id
- Tested in beams
- Robust design: stainless steel tubes

Physics Reach (CKM) in 10^7 s

Reaction	$\mathcal{B}$(B)(x10^{-6})	# of Events	S/B	Parameter	Error or (Value)
$B^o \to \pi^+\pi^-$	4.5	14,600	3	Asymmetry	0.030
$B_s \to D_s K^-$	300	7500	7	γ	8^o
$B^o \to J/\psi K_S$ $J/\psi \to \ell^+\ell^-$	445	168,000	10	$\sin(2\beta)$	0.017
$B_s \to D_s \pi^-$	3000	59,000	3	x_s	(75)
$B^- \to D^o (K^+\pi^-) K^-$	0.17	170	1		
$B^- \to D^o (K^+K^-) K^-$	1.1	1,000	>10	γ	13^o
$B^- \to K_S \pi^-$	12.1	4,600	1		< 4^o +
$B^o \to K^+\pi^-$	18.8	62,100	20	γ	theory errors
$B^o \to \rho^+\pi^-$	28	5,400	4.1		
$B^o \to \rho^o\pi^o$	5	780	0.3	α	~4^o
$B_s \to J/\psi\, \eta$, $J/\psi \to \ell^+\ell^-$	330	2,800	15		
$B_s \to J/\psi\, \eta'$	670	9,800	30	$\sin(2\chi)$	0.024

Endorsements

- Based on our sensitivities, and implementation in 2009 a HEPAP subpanel wrote: "P5 supports the construction of BTeV as an important project in the world-wide quark flavor physics area. Subject to constraints within the HEP budget, we strongly recommend an earlier BTeV construction profile and enhanced C0 optics"
- Using identical conditions BTeV was included as a near term priority in the category of "Highest Scientific Importance and Near-term Readiness for Construction," in the "Facilities for the Future of Science: A Twenty-year Outlook" report of the Office of Science.

Kinds of Requirements

- One set of requirements is based on the physics performance we want the detector to provide
- A second set is internal to the detector subsystem of interest and tells how each individual piece needs to perform (i. e. the efficiencies of PM tubes, or noise on electronics)
- Yet a third set is based on safety rules (ES&H)
- I will concentrate on the first set here

Fundamentals

- Luminosity up to $2\text{x}10^{32}$ $cm^{-2}s^{-1}$
- Mean number of interactions per crossing of 6 (thus allowing for 396 ns bunch spacing)
- Time between bunches < 100 ns (thus allowing for 132 ns bunch spacing)
- Radiation Resistance for at least 10 years on all detector components

High Level Requirements

- Charged Tracks
  - Angular acceptance: 10 - 300 mr
  - $p > 3$ GeV/c
  - Tracking efficiency > 98%
  - Mass resolution < 50 MeV/c
  - Primary vertex resolution < 100 μm
- Trigger efficiency & rejection
  - $\varepsilon > 50$ % for all B decays with ≥ 2 charged tracks
  - $\varepsilon > 20$ % for all B decays with 1 charged track
  - Trigger rejection > 98% on light quark events (Level I), and 99.95% at Level III with only a 10% further loss in b efficiency
  - Maximum data rate to archival storage < 200 Mbyte/sec

Hadron & Lepton Identification

- π/K separation $\geq 4\sigma$ for momenta 3 - 70 GeV/c
- p/K separation $\geq 3\sigma$ for momenta 3 - 70 GeV/c
  - These allow for π/e & π/μ separation at 4σ level up to ~23 and ~17 GeV/c, respectively
- positive μ identification from 5 - 100 GeV/c with a fake rate < 10^{-3} and an independent momentum determination with resolution

$$\frac{\sigma_p}{p} = 19\% \oplus 0.6\% \times p$$

Electromagnetic Calorimeter

- Radius up to 160 cm ~220 mr, with hole for beam ~10 mr
- Range E > 1 GeV
- Energy resolution

$$\frac{\sigma_E}{E} < \frac{2\%}{\sqrt{E}} \oplus 1\%$$

- Position resolution

$$\sigma_x < \frac{4\ \mathrm{mm}}{\sqrt{E}} \oplus 1\mathrm{mm}$$